Growth as Related to Specific Gravity and Size of Seed

BY

Mary E. Renich

Reprinted from Transactions of the Illinois State Academy of Science, Vol. 14, 1921.

Growth as Related to Specific Gravity and Size of Seed

BY

MARY EMMA RENICH

A. B. University of Illinois, 1911

A. M. University of Illinois, 1912

THESIS

Submitted in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

IN BOTANY

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1920

Reprinted from the Transactions of the Illinois State Academy of Science, Vol. 14, Pages 109-139.

GROWTH AS RELATED TO SPECIFIC GRAVITY AND SIZE OF SEED*

MARY E. RENICH

TABLE OF CONTENTS

I. INTRODUCTION

The influence of the size and of the weight of seed on the resulting crop has been a subject of investigation for many years. The evidence gathered from the literature in this field seems to show that large, heavy seeds give the best returns. A considerable number of investigators find that their results are rather conflicting. Dehérain et Dupont (4) maintain that it is only when the difference in the weights of the seeds used is great, that there is a definite advantage in favor of the heavier seed. Meyer, C. H. (13) says that the question of advantage in the use of large and small seeds as associated with yields is inconclusive. Leighty, C. E. (11) condemns the method of selecting the largest seed without consideration of the character of the mother plant; and Love, H. H. (12) concludes from his results that the heavy grains of wheat and oats come from the tallest and heaviest yielding plants. Johannsen, W. (9) in his work on inheritance of weight shows that, in a population of beans, the heaviest daughter-beans

*This paper is the thesis, somewhat condensed by the omission of several tables, submitted by the author in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

are the progeny of the heaviest mother beans, but that in a pure line this is not necessarily true. DeVries (5), on the other hand, thinks that the size and the weight of seed are primarily the result of nutrition, in the broad sense, rather than the result of inheritance.

In so far as specific gravity is concerned, another series of experiments has been carried on. Haberlandt, F. (6) found in working with wheat, oats, etc., that the denser grains yielded the heavier returns in grain, and that the less dense ones yielded the greater amount of straw. According to Wollny, E. (17) the absolute weight and not the specific gravity is the only true index of the value of the grain. Clark, V. A. (2) found that, except in the case of oil bearing seeds, the larger number of good seeds is near the upper limit of the specific gravity for the variety. He concludes, however, that specific gravity is of less importance than size in seed selection.

While each of these fields has been investigated by many workers, a few have considered the combined effect of size and of specific gravity in seed collection. Among the latter is Sanborn (16). He sorted wheat according to size and then separated the large grain into two groups by the use of a brine solution. The yield from his lighter grain surpassed that from his heavy grain. Degrully, L. (3) in working with corn, discarded all the very small and poorly formed grains. He then separated out the lightest one fourth by means of a sodium nitrate solution. He states that the difference of the results in favor of the heavy grain was remarkable.

Practically all experiments have been carried on under field conditions. They have had for their chief aim the influence of specific gravity and of size of seed on crop production. A few tests have been made by Kiesselbach and Helm (10) to find the relation of the "sprout value" to the yield of small grain crops. The term "sprout value" is defined by the authors as, "The moisture-free weight of the maximum plant growth derived from the seed when planted and grown in a non-nutritive quartz medium and in absolute darkness."

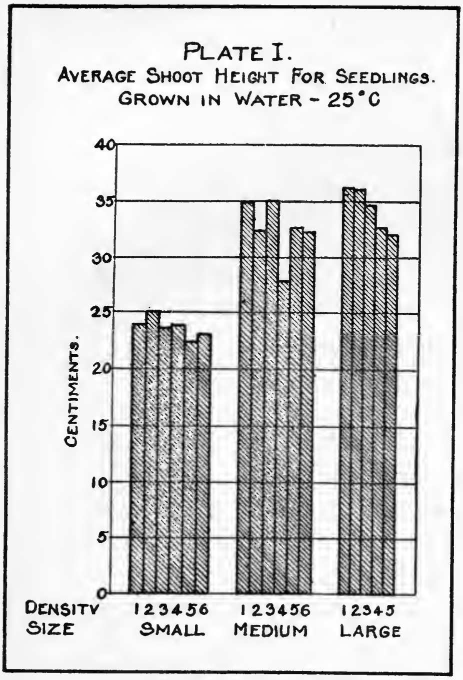
PLATE I.
AVERAGE SHOOT HEIGHT FOR SEEDLINGS.
GROWN IN WATER - 25°C
CENTIMENTS.
40
35
30
25
20
15
10
5
0
DENSITY 123456 123456 12345
SIZE SMALL MEDIUM LARGE

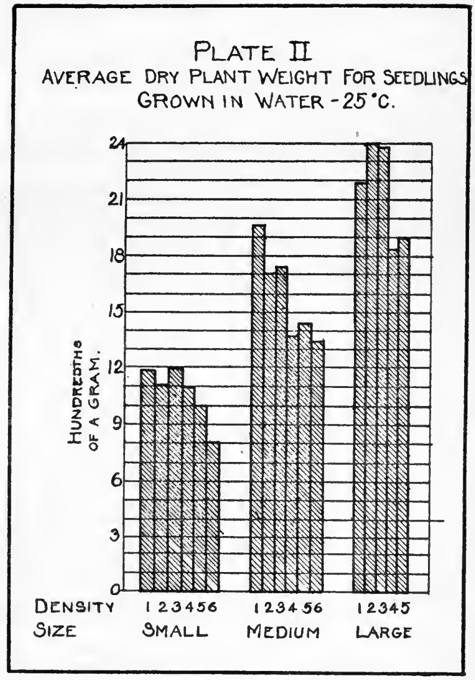
PLATE II
AVERAGE DRY PLANT WEIGHT FOR SEEDLINGS
GROWN IN WATER - 25°C.
HUNDREDTHS OF A GRAM.
24
21
18
15
12
9
6
3
0
DENSITY 123456 123456 12345
SIZE SMALL MEDIUM LARGE

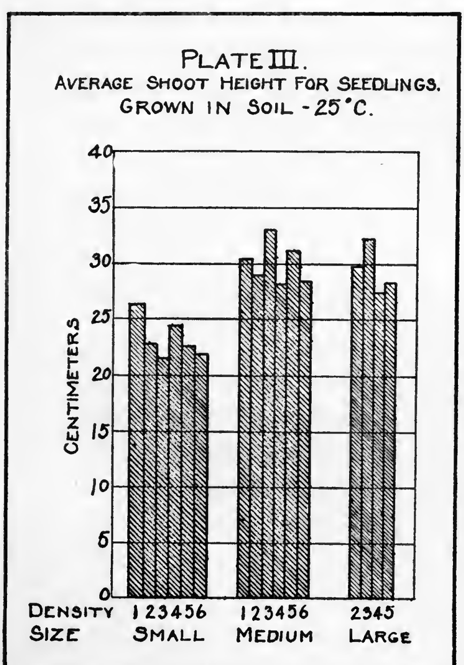
PLATE III.
AVERAGE SHOOT HEIGHT FOR SEEDLINGS.
GROWN IN SOIL - 25°C.
CENTIMETERS
40
35
30
25
20
15
10
5
0
DENSITY 123456 123456 2345
SIZE SMALL MEDIUM LARGE

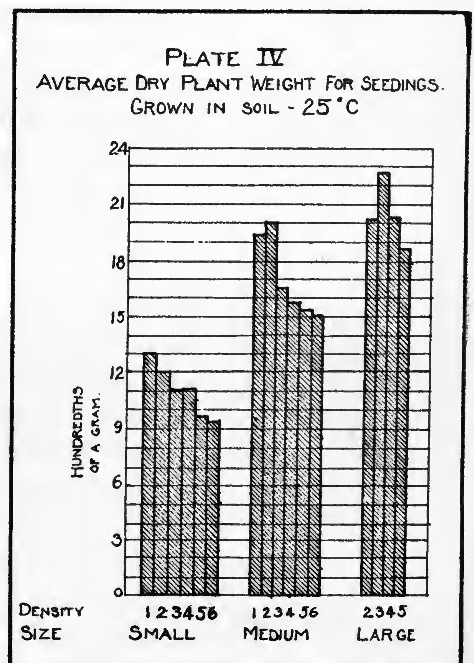
PLATE IV
AVERAGE DRY PLANT WEIGHT FOR SEEDINGS.
GROWN IN SOIL - 25°C
HUNDREDTHS OF A GRAM.
24
21
18
15
12
9
6
3
0
DENSITY 123456 123456 2345
SIZE SMALL MEDIUM LARGE

The problem of finding how much growth, due solely to the reserve food in the seed, will take place in seedlings from seeds separated according to specific gravity and to size has not, as yet, been studied. The solution of this problem is the object of the experiments here recorded.

II. MATERIALS AND METHDOS

(1) Selection and Separation of the Seed Used.

The common garden bean because of its ready adaptability to laboratory conditions was chosen for these experiments. In the spring of 1919, ten pounds of Burpee's Red Valentine seed of the season of 1918 were divided according to their specific gravity into six groups. This separation was made by means of solutions of chemically pure sodium nitrate dissolved in distilled water. A preliminary test showed that few seed sank in a solution of 1.32 specific gravity, or floated in one of 1.12. The solutions used consequently range from 1.32 to 1.12 specific gravity. They were prepared with the use of a Twaddell hydrometer, corrected for 60° F., and both seeds and solutions were kept at this temperature while testing. The solutions made up differed from each other in specific gravity by .05 and, in use, were not allowed to vary by more than .005.

A few seeds were placed in a small tea strainer, dipped into 95% alcohol to remove the air film and then transferred to a larger strainer immersed in a solution of sodium nitrate of 1.32 specific gravity. The seeds which floated were removed by a second small strainer and they as well as the ones which sank were rapidly and thoroughly washed, and spread out on towels in a warm room to dry. The ones which sank, after drying, were stored in glass jars for future use. After all the seeds had been passed through the solution of greatest density (1.32 sp. gr.), those which floated were taken in a similar manner through the solution next lower, solution of 1.27 sp. gr., etc. By this method six groups of seeds were obtained. These groups are designated in the discussion and in the tables as follows:

Density 1, seeds which sank in a solution of 1.32 sp. gr.;

Density 2, seeds which sank in a solution of 1.27 sp. gr.; (range from 1.32–through 1.27);

Density 3, seeds which sank in a solution of 1.22 sp. gr.; (range from 1.27–through 1.22);

Density 4, seeds which sank in a solution of 1.17 sp. gr.; (range from 1.22–through 1.17);

Density 5, seeds which sank in a solution of 1.12 sp. gr.; (range from 1.17–through 1.12);

Density 6, seeds which floated in a solution of 1.12 sp. gr. By this method the seeds were exposed to the solution but a few seconds and, as germination and growth tests showed, suffered no harm from the process.

The seeds passed through the successive solutions varied in length from 8.3 mm. to 18.5 mm. These were divided into three groups of the following respective lengths:

Large seeds, range in millimeters from 18.5 to 15.1; medium seeds, range in millimeters from 15.1 to 11.7; small seeds, range in millimeters from 11.7 to 8.3.

(2) Treatment of Seedlings.

Twenty-four seeds of each group were individually weighed and measured. Twelve were placed in beakers of sphagnum, the others were planted, one quarter of an inch below the surface of the soil, in small flower pots. In putting the seeds to germinate, the micropyle end was always placed down thereby avoiding unnecessary curving of the seedling. The beakers and the pots were kept in covered metal cases at a temperature of 20°C during germination. When the seedlings in the sphagnum started to put forth secondary roots they were transferred to small aspirator bottles filled with tap water. This water is essentially a nutrient solution as the chemical analysis given by the Illinois State Water Survey (8) shows. The seedlings were held in place by means of fine aluminum wire and by a support which was fastened to the neck of the bottle. The bottles were then placed into the cases where they were left until the seedlings were ready for use. The water in the bottles was renewed on alternate days.

When the seedlings were one or two centimeters in height, the pots or bottles were placed into rectangular metal cases consisting of a lower part fifteen centimeters in height and a tall upper part which fits down over the former leaving an air space of one centimeter between the lower and upper parts. By this means all light was excluded but air exchange was not prevented. These small cases were placed in special large constant temperature cases designed by Professor Charles F. Hottes. The seedlings were removed from the cases daily, measured and watered. During the period of measuring, approximately ten minutes, the seedlings were exposed to the light and to the temperature (20°C) of the laboratory. Seedlings deformed or otherwise abnormal were discarded. They were grown in series at temperatures 20°, 25° and 30°C. The large seeds, of which only a very limited number were on hand, were grown at 25°C only.

All measurements were taken beginning two and one-half centimeters above the root origin. If the entire height of the shoot is desired, two and one-half centimeters must be added to the total height of the shoot as recorded in the tables. In those cases in which the cotyledons were not opposite, the length of the hypocotyl was measured to the insertion of the lower cotyledon. The length of the internodes were taken from the lower part of one node to the lower part of the next higher or, in the case of the upper internode, to the growing point. A centimeter rule was used and the measurements were read to the nearest millimeter. From the record of these daily measurements, the daily growth increments given in the tables were obtained.

When a shoot showed no growth since the previous day its diameter, one centimeter below the insertion of the cotyledons, was taken by means of a vernier callipers. The seedling was then removed from the soil or the water, the root was washed, superficially dried, and separated from the shoot. Then the fresh weights of root and shoot were obtained. These parts were dried to constant weight in an electric oven. All weights were read to the fourth decimal place.

The data for the several series are given in *Tables 1 to 47. Data are given for individual seedlings grown at the temperature 25°C; for those grown at 20° and 30°C, the data given consists of averages, taken in most cases from eight seedlings. In a few cases, where germination was poor, or seedlings were discarded because of abnormality or accident, the averages include a smaller number. Measurements of seedlings were taken to tenths of centimeters, but the calculation of averages was made to the third decimal place and are recorded to the second.

III. DISCUSSION

Daily observation of the seedlings made evident a striking correlation between the amount and rate of growth and the specific gravity and size of the seed. So marked and regular is the correlation that it was possible, as a rule, to select the seedlings from seeds of certain densities and sizes by their general appearance. This was especially true for the seedlings from seeds of Densities 2 and 3, for these appeared more uniform in size and consequently in the rate of growth. They were also more sturdy and of a deeper yellow color than those from seeds of the lower densities. Now and then a group from Density 4 would be mistaken for those of the higher densities. This is apparently in agreement with the results that Degrully (3) obtained in his work with wheat. He found that the plants from the denser grains were greener, more vigorous, and, during their early growth, showed a great superiority over those from the less dense grains. Because of heavy rains, his plants of both groups suffered greatly from rust and he was unable to make comparisons of the final growth. A study of the data as recorded in the tables shows that the differences noted in the seedlings are not differences of appearance only.

Because seedlings from seeds of all sizes and densities were grown at 25°C the *Tables 1 to 17 and 21 to 36 have the data given for individual seedlings. A comparison of individuals is not undertaken because that would lead to a study of individual variation. In order to show the superiority of some groups over others, the groups will be compared in respect to their average, maximum and minimum values. Because of differences between the seedlings grown in water and those grown in soil each culture will be studied separately.

1. Relation of Growth to Specific Gravity of Seeds at 25°C.

a. Water Culture.

Size.—A comparison of average values for the seedlings grown in water, at temperature 25°C can be most readily obtained by a study of Tables 18 to 20; for the maximum and minimum values, *Tables 1 to 17.

An examination of the average values for the heights of the shoots shows that the greatest and second greatest average heights of seedlings from seeds of each of the three size groups are for seedlings from seeds of Density 1, 2 or 3. These average heights are graphically shown in Plate I. In the hypocotyl and first internode no correlation between average length and specific gravity of seed is apparent, but a direct relation does exist between these factors in the second and third internodes, in that, the lower the density of the seed, the shorter the internodes. Fourth internodes developed only in seedlings from seeds of Densities 1 and 3. There is also a direct relation between average diameter of seedlings and specific gravity of the seeds; the seedlings from the denser seeds are larger in average diameter than those from the less dense.

In studying the maximum and minimum values of seedlings from seeds of the several densities, *Tables 1 to 17 are used. For the small seeds, the greatest shoot height is that of a seedling from a seed of Density 5. The second in height is from a seed of Density 3. For the medium seeds, the three tallest seedlings of the series are from seeds of Density 3. The two tallest seedlings from the large seeds are of seeds of Density 2, the third tallest, from a seed of Density 3.

As in the case of the average length of hypocotyls and first internodes so here, there exists no definite relation between maximum lengths of seedlings of the different groups and specific gravity of seed. In the second and third internodes, the maximum lengths for the several series are in every case, in seedlings from seeds of one of the three highest densities. There is a marked difference between the maximum lengths of these internodes in the seedlings from seeds of the higher and lower densities. While in average values, the diameter of the shoot varied with the density, this does not hold true for the maximum values.

With but few exceptions the minimum values for shoot height and diameter are found in seedlings from seeds of Density 5 or 6, usually the latter.

From these comparisons we may conclude that, for seedlings grown in water at a temperature of 25°C.

(1) The greatest height and diameter of shoot are found in seedlings from seeds of Densities 1, 2 and 3; in Density 2 or 3 more often than in 1;

(2) The lower the density, the shorter the second and third internodes.

Weight.—That weight is related to density is clearly seen from a study of the tables. The average weight values are considered in Tables 18 to 20. In the case of the fresh weights of roots, shoots and plants for seedlings from the large and the small seeds, the three greatest average weights for each size group are found in the seedlings of the three highest densities. For the medium seeds, the highest average fresh root weight is in the seedlings from seeds of Density 4, but the second highest is in those of Density 1. The highest average values for fresh shoot and fresh plant weights for the seedlings from these medium seeds are in those of the three highest densities as was the case for the seedlings from the small and large seeds.

The maximum fresh root weight for the small seeds is found in a seedling from a seed of Density 3; for the medium seeds from a seed of Density 4; and for the large seeds, from a seed of Density 2. The maximum fresh shoot weight for the small seeds is that of a seedling from a seed of Density 1; for medium seeds, of Density 1; for large seeds, of Density 3. The maximum fresh plant weights for seedlings from the small and the medium seeds are for those from seeds of Density 1; for the large seeds, for one from a seed of Density 2. The minimum fresh weights are usually the weights for seedlings from seeds of Density 5 or 6.

A better idea of the actual amount of growth can be obtained from the dry weights than from the fresh weights.

For the seedlings from seeds of each size group, the three highest average dry weights for roots, for shoots and for plants, are in the seedlings from seeds of the three highest densities. These average weights, however, do not vary directly as the densities, for the highest value is sometimes in seedlings from seeds of Density 3, sometimes in those from seeds of Density 1 or 2. Plate II represents the average dry weights for the seedlings of each group.

The maximum dry root weights for seedlings from the small, the medium and the large seeds are in seedlings from seeds of Densities 3, 1 and 2 respectively. The maximum dry shoot weights, and also the maximum dry plant weights are for seedlings from seeds of Density 1, for those from the small and the medium seeds, and Density 2 for those from large seeds. The minimum dry weights are, as a rule, in seedlings from seeds of Densities 5 and 6.

From these facts we may conclude:

(1) That, with the exception of the roots from the medium seeds, the greatest fresh weights are in seedlings from seeds of the three highest densities.

(2) The greatest dry weights are also in seedlings from seeds of the three highest densities.

Comparison of Weights.—There is little correlation between the relation of dry to fresh weight and the specific gravity of the seeds. It is apparent, however, that in the seedlings from seeds of Density 3 the average percentage which the dry weights of root, shoot and plant is of the fresh weights of the corresponding members is as great, sometimes greater, than that of any other density.

The average percentage which the dry plant weight is of the seed weight is always higher for the seedlings of seeds of Density 6 than for those from seeds of Density 1; in most cases it is also higher than for those from seed of Density 3. This higher percentage shows that although in size and weight the seedlings from the seeds of Density 6 are inferior to those of other densities, the seedlings from seeds of Density 6 appear to make the best use of the reserve food in the seed.

Rate of Growth.—Not only is the amount of growth related to the specific gravity of the seed but there also exists a relation between the rate of growth and the specific gravity of seed. Considering the rate of growth as shown by the daily growth increments we find that, in general, seedlings from seeds of the higher densities have a greater growth rate than those from seeds of the lower densities. The greatest average daily increment for the small seeds, 5.8 cm, was made on the second day after being placed in the constant temperature case by the seedlings from seeds of Density 6. For the medium seeds, the greatest average daily increment, 7.63 cm, was made on the second day by seedlings from seed of Density 3; and for the large seeds, an average daily growth of 6.85 cm was made on the third day by seedlings from seeds of Density 1. The maximum daily growth increment of the seedlings from small seeds is 7 cm, made on the second day by a seedling from a seed of Density 3; the maximum for the medium seeds is 9.3 cm, made on the second day by a seedling also from a seed of Density 3. For the large seeds, the maximum increment 7.7 cm was made on the third day by a seedling from a seed of Density 2. The average rate of growth often decreases more rapidly in the seedlings from seeds of the lower densities and although the total height of the seedlings from these densities is less than that for those from the denser seeds, growth usually continues for as many days as in seedlings from the seeds of higher densities.

b. Soil Culture.

The data for seedlings grown in soil at temperature 25° C is given in Tables 21 to 40. Tables *21 to 36 contain the records of the individual seedlings while the average values are shown in Tables 38 to 40. Because of the limited number of large seeds of Densities 1 and 6 none were grown in soil.

Size.—Proceeding as in the discussion of the seedlings grown in water, we find the greatest average shoot heights for the small, the medium and the large seeds respectively, are for seedlings from seeds of Densities 1, 3 and 3. The highest shoot from the small seeds is that of a seedling from seed of Density 4, the second highest, of Density 1; the two highest for the medium seeds are from seeds of Density 3; the highest for the large seeds is from Density 2 while the second highest is from Density 3. The minimum value for each size group is in a seedling from seed of the lowest density.

No correlation exists between density and average and maximum length of hypocotyl and first internode. The lengths of the second and third internodes vary as the density of the seeds. No seedlings grown in soil developed a fourth internode. As to the diameter, we find the average size varies as the density of the seed; the maximum values are also in the diameters of the seedlings from seeds of the higher densities.

In so far as size of seedlings is concerned, the results agree in general with those for water grown seedlings,—

(1) The greatest height and diameter of shoot is found in seedlings from the seeds of Densities 1, 2 and 3. More often in seedlings from Densities 2 or 3 than Density 1.

(2) The length of the second and third internodes vary as the density of the seed.

Weight.—There is more variation in the fresh weight of soil-grown seedlings than in those grown in water. This is especially true in the root weight. In the roots of seedlings from small seeds the greatest average and maximum weights are for those from the higher densities and the minimum weights are in those of lower densities, but no general relation seems to exist between fresh root weight and specific gravity for seedlings from the medium and large seeds.

In the fresh shoot weights we have the greatest average weights for the small, the medium and the large seeds in those from seeds of Densities 1, 2 and 3 respectively. The maximum fresh weight for each size group is in a seedling from a seed of Density 3 while the minimum weights are in those from Densities 5 or 6, usually 6. In the fresh plant weights we find the same order as in the shoot weights the greatest average weights for small, medium and large seeds are in seedlings from seeds of Densities 1, 2 and 3 respectively; while the maximum weight for each group is in a seedling from a seed of Density 3; the minimum weights are in those of Density 5 or 6, usually 6.

In the dry weights we find a definite relation between density and weight. This correlation with plant weight is graphically represented in Plate III. Without exception the highest average and maximum weights for each size group are in the seedlings from seeds of Densities 1, 2 or 3. This statement holds true for dry weights of root, shoot and plant. Moreover, the second highest average and maximum weights are in most cases also in seedlings from seeds of these higher densities. The lowest average and minimum weights are for seedlings from seeds of the lower densities.

Comparison of Weights.—The facts pointed out for seedlings grown in water with respect to correlation between dry and fresh weights and specific gravity of seed hold true for those grown in soil. The seedlings from seeds of Density 6 appear to lead in making the best use of their reserve food as was the case in the water culture.

Rate of Growth.—A study of the daily growth increments also points to a superiority of the seedlings from the denser seeds. In the case of average daily increments (Tables 37-39) we find the greatest average increment for the small seeds is 7.56 cm on the third day for seedlings from seed of Density 1; for medium seeds, 8.9 cm on the second day by those from seeds of Density 3; for large seeds, 7.67 cm on the second day by those from seeds of Density 1. From *Tables 21-36 we obtain as maximum daily increments, for small seeds, 8.5 cm on the third day by a seedling from a seed of Density 1; for medium seeds, 10 cm on the second day by two seedlings from the seeds of Density 5 and one from those of Density 3; for the large seeds, 10.1 cm on the second day by a seedling from seed of Density 1.

Summing up the results from the data for seedlings grown in water and in soil at 25°C we find the following relations exist between specific gravity and growth:

(1) The greatest height and diameter of shoot are found in the seedlings grown from seeds of the three highest densities;

(2) The higher the density of the seed, the longer the second and third internodes;

(3) As a rule, the seedlings from the denser seeds have the highest fresh weight;

(4) The greatest dry weight is always found in seedlings from seeds of the three highest densities;

(5) The seedlings from the higher densities show, on the whole, a greater rate of growth than do those from seeds of the lower densities.

2. Relation of Growth to Size of Seed, at 25°C.

Size.—That a definite relation exists between size of seed and amount and rate of growth is shown beyond a doubt by the results of these experiments. For both water and soil cultures the seedlings from small seeds are smaller than those from medium and large seeds in height and in diameter of shoot. This fact in regard to shoot height is clearly shown in Plates I and III. From these plates we see that the seedlings from small seeds are not only shorter than those from medium seeds of the same density but the seedlings from the small seeds of the highest density are shorter than those from the medium seeds of the lowest densities. Both the numerical data and these plates show that there is less difference in height between the seedlings from medium and large seeds than there is between those from medium and small seeds. The average heights for seedlings from the medium seeds from Densities 3 and 5 (Table 19) are greater than those from the large seeds (Table 20) of the same densities. The maximum heights for seedlings of Densities 1, 3 and 5 are also greater than the maximum heights for the large seeds of the same densities.

There is a greater difference between the diameters of the seedlings from small and medium seeds than between those from medium and large seeds. The lengths, both average and maximum, of the hypocotyls in seedlings from the medium seeds are greater than those of the small or large seeds. There is little difference in the case of soil grown seedlings in the hypocotyl lengths of seedlings from small and large seeds. There is less difference between the length of the second and third internodes of seedlings from medium and large seeds than between those from medium and small of the same density.

Weight.—From the data given for fresh root weight (Tables 18 to 20) for water culture, we find that the average weight for seedlings from the small seeds of Density 3 is greater than that of those from the medium or large seeds of like density. The average weight for seedlings from small seeds of Density 2 is greater than that of those from the medium seeds of this density. Again, the average weight for seedlings from medium seeds of Densities 4 and 5 is greater than that of those from large seeds of these respective densities. The fresh weights for shoots and plants vary, for equal densities, as the size of the seeds.

The dry weights for seedlings grown in water also show a relation to size of seed. In the roots of seedlings, those from the small seeds of Density 3 nearly equal in average, minimum and maximum dry weights the roots from medium seeds of equal density. As between medium and large seeds, seedlings from medium seeds of Density 4 surpass those from the large seeds in minimum and average weight; and seedlings from medium seeds of Density 5 surpass those from large seeds in average and maximum dry root weight. In general, however, the weights of seedlings grown in water from seeds of equal densities vary as the size of the seed. The comparison of average dry plant weight is given graphically in Plate II.

Turning now to the data for average values in soil grown seedlings (Tables 37 to 39) we find that, except for the average weights of seedlings from medium seeds of Density 2, all average fresh weights vary as the size of the seeds provided they are equal in density. In the exception just cited the average weights for seedlings from medium seeds is greater than that for those of the larger seed in the case of root, shoot and plant weights. With but one exception, again in Density 2, all dry root, shoot and plant weights vary as the size of the seeds provided we compare seedlings from seeds of the same density. Plate IV represents the average dry plant weights for soil grown seedlings.

Comparison of Weights.—In general, the percentage which the dry weight of shoot and plant is of the fresh weight of like member is greater for seedlings from the large seeds than from the medium or the small seeds. The percentage which the dry plant weight is of the seed weight is also higher for seedlings from the large seeds than from the medium or small seeds.

Rate of Growth.—That the rate of growth is also influenced by the size of the seed is shown by the daily growth increments. For water culture seedlings the average daily increments (Tables 18 to 20) on the second and third day are greater for the seedlings from medium seeds than for those of either small or large seeds of like density. The greatest average daily increments, except in seedlings from large seeds of Densities 1 and 2, are found in the seedlings from the medium seeds. The maximum daily increment occurs on the second day in seedlings from the small and the medium seeds but not until the third day for those from the large seeds. The same superiority in the rate of growth for seedlings from the medium seeds grown in soil is seen from Tables 37 to 39.

In so far as amount and rate of growth are influenced by the size of the seed, we find:

(1) The amount of growth varies with the size of the seed;

(2) There is more variation in amount of growth between small and medium seeds than between medium and large seeds;

(3) The rate of growth of seedlings from medium seeds is greater than that for those of small or large seeds of equal density.

3. Temperature in Relation to Specific Gravity and Size of Seed.

It is not the intention to discuss in detail growth at 20° and 30°C, but rather to determine whether conclusions drawn for temperature 25° may be applied to seedlings from similar seeds grown at 20° and 30°C respectively. Because of the limited number of large seeds no data is available save at 25°C. The discussion will be confined to a consideration of average values. The data for seedlings grown at 20°C are found in *Tables 40 to 43, that for those grown at 30°C in *Tables 44 to 47.

a. Growth as Related to Specific Gravity.

A study of the above tables shows that with but few exceptions the conclusions drawn for the relation of growth to the specific gravity of the seed, for temperature 25°C are also true for temperatures 20° and 30°C. At 25°C there was no correlation evident between length of hypocotyl and specific gravity of seed; at 20°, however, the greatest average length of hypocotyl in seedlings grown in soil appear in those of Densities 1, 2 and 3.

At 25°C, the percentage of the dry plant weight to the seed weight is higher for seedlings from seeds of Density 6 than for those from seeds of Densities 1 and 2. At 20°C, this is true only for seedlings grown in water, and at 30°C, it applies solely to seedlings from medium seeds grown in water.

b. Growth as Related to Size of Seed.

The seedlings grown at 30°C show the same correlation between growth and size of seed as is shown by those grown at 25°C. For the seedlings grown at 20°C, however, the following points of difference seem evident:

(1) The average heights and average weights of seedlings from small seeds are more nearly equal to the similar average values of seedlings from medium seeds of like densities, at 20°C than at 25°C. In a few cases the average values for seedlings from small seeds exceed those for seedlings from medium seeds.

(2) From the total dry weight it may be inferred that at 20°C the seedlings from small seeds use their reserve material to better advantage than those from the medium seeds.

(3) At 20°C, the greater rate of growth is shown by seedlings from the small seeds.

4. *Some Comparisons of Seedlings Grown in Water and Soil.*

a. Water Content.—The relation of the dry weights to the fresh weights shows a difference in the relative water content of seedlings from seeds of equal size and density grown in water and soil. The percentage of the dry root weight to the fresh root weight is greater for the seedlings grown in soil; that of the dry shoot and plant weights to the fresh shoot and plant weight is greater for those grown in water.

The stems of the seedlings grown in soil were brittle while those grown in water could be coiled without breaking.

b. Roots.—The root system of the seedlings grown in soil was very much larger than that of seedlings grown in water. In the majority of the soil culture seedlings the primary root soon ceased to elongate and the main part of the root system consisted of several long, lateral roots arising from near the base of the main root. In the seedlings grown in water the primary root, although comparatively short, was the main part of the root system. Several short lateral roots developed near the base of the root and also lower down on the primary root.

5. *Equation of Growth.*

A study of the tables here recorded shows that the equation of growth given by Blackman, V. H. (1) does not apply to seedlings grown in the dark. In the case of each seedling grown under the conditions of these experiments the final dry weight is much less than the initial dry weight of the seed. This would mean, if Blackman's equation held true, that there had been no growth in these seedlings.

6. *Correlation of Weight and Position of Cotyledons.*

Harris (6), in an article on Interrelationships in Phaseolus, states that the green and dry weights of the primordial and first compound leaves of plants whose cotyledons are not inserted at the same level of the axis are less than those of normal plants. No such correlation exists for the fresh and dry weights of the seedlings recorded here. Numerous examples of this "abnormality" as Harris calls it, occurred but no account was taken of them unless the difference in level was at least 2mm; in some exceptional cases it was as much as 18mm. That no such correlation exists in these seedlings is shown by a comparison of the root, shoot, and plant weights of an abnormal seedling with the corresponding average weights of the group to which it belongs. Such a comparison shows that the weights of the seedling are sometimes above and sometimes below the average weights.

7. *Quintile Distributions.*

An article by Pearl and Surface (14) on "Growth and Variation in Maize" states, on page 120, "There is, then, a marked tendency for the plants which were relatively small at the beginning of the season to have remained, on the average, relatively small throughout most of the season." Or, to quote further (page 170), "Extreme variants at the beginning of the season tend strongly, on the whole, to remain extreme variants during the whole season." This tendency is said to be due to the effect of internal rather than to external stimuli.

Reed, (15) in studying growth and variability in Helianthus, follows the method of argument of Pearl and Surface and concludes that, "Plants which started in a given quartile showed a well-marked tendency to remain in that quartile during the entire grand period of growth. Plants which were small at maturity were generally small from the beginning, those which were large at maturity had a well-marked superiority from the start." He, too, thinks plants show this tendency because of inherent factors.

In order to determine whether the seedlings used in the present experiments revealed similar traits the data for all seedlings which were grown in water and which were placed in the 25°C temperature case on the sixth day after placing them to germinate, were collected. A group of 75 seedlings containing individuals from seeds of all densities and sizes was thus obtained. The heights of these seedlings on each successive day and the density and size of the seeds from which each grew are given in *Table 49.

*It has been found necessary in the publication of these experiments to omit Tables 1-17, 21-36, 40-49. These tables can be found in the original thesis at the Library of the University of Illinois.

The seedlings are arranged and numbered according to their size on the first day, that is, on the day they were placed in the constant temperature case and six days after planting. Following the method given in the articles cited, these 75 seedlings are arranged in five groups, or quintiles, according to their size on the first day. In order to avoid having seedlings of the same size fall in two different quintiles, the number of plants in the quintiles varies. Thus, Quintile I contains the 15 smallest seedlings on each day of measurement. Quintile II contains the 16 next larger; Quintile III, the 17 next larger; Quintile IV, the 12 next; and Quintile V, the 15 largest ones. The number of seedlings in the respective quintiles was maintained during the growth period. In but two cases, after the initial distribution, did two seedlings fall on the separating line of contiguous quintiles. In these cases one of the seedlings was arbitrarily placed in the next highest quintile. The quintile distribution for each successive day for seedlings starting in the several quintiles is given in Tables 50 to 54. These tables give the total number of distributions, excluding those of the first day, when, of course, all distributions were in the particular quintile to which the seedlings were originally assigned, and also the mean quintile position for each day. A study of the tables shows that by the sixth day only 3 of the 15 seedlings which started in Quintile I are still in this quintile and by the tenth day only 2 remain. Three of the 15 reach Quintile V by the ninth day. Out of the total of 165 distributions only 42, or 25.5% are in Quintile I. The mean quintile position for these seedlings changes from 1 on the initial day to 3 on the eleventh and twelfth days. This final mean quintile position is above the general mean, which owing to the difference in the number of seedlings in the several quintiles is 2.95. Only 18.8% of the total number of distributions for seedlings starting in Quintile II fall in this quintile. For Quintile III the per cent is 20.9; for Quintile IV, it is 25; and for Quintile V, 25.5. The mean quintile position for seedlings starting in Quintile V drops from 5 on the first day to 2.87 on the ninth day. The curves for the mean quintile positions on the successive days are plotted in Plate V. As is to be expected where the variation can be in either

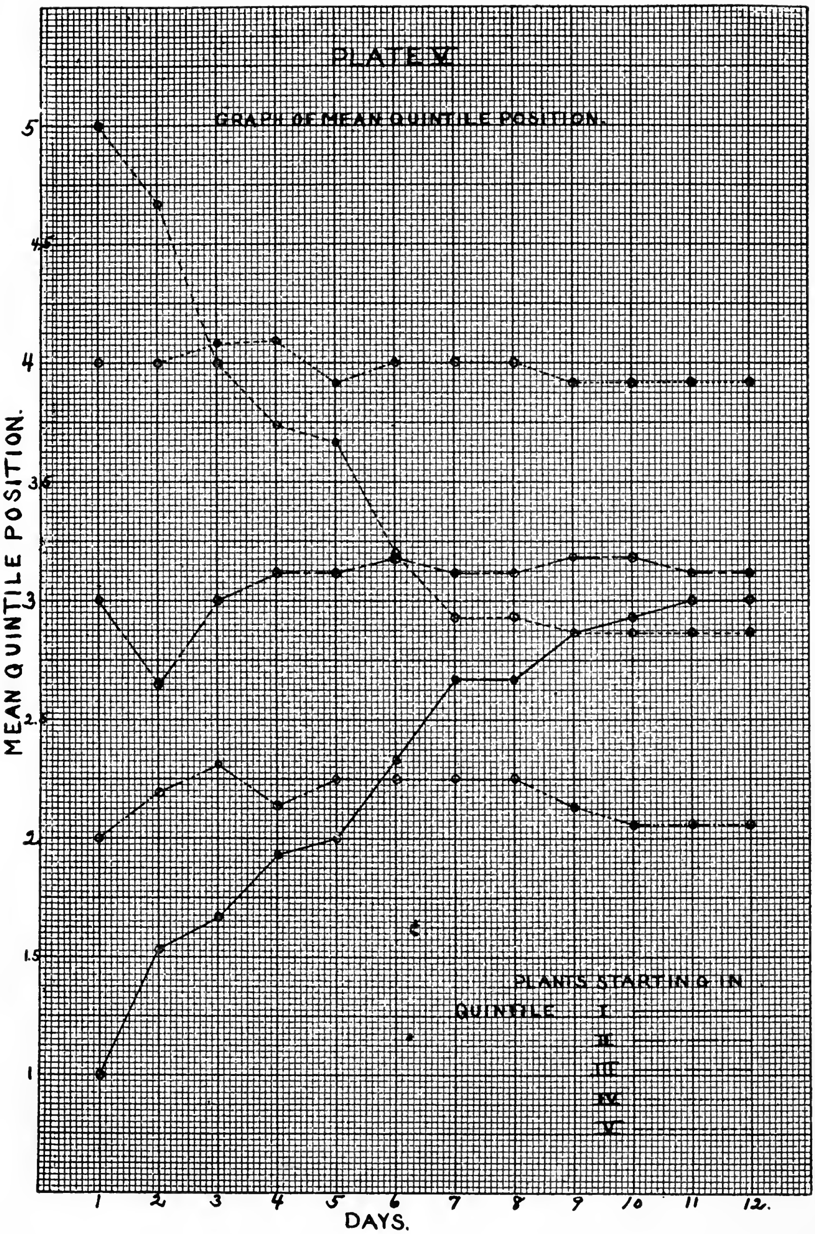
PLATE V
GRAPH OF MEAN QUINTILE POSITION.
MEAN QUINTILE POSITION.
5
4.5
4
3.5
3
2.5
2
1.5
1
1 2 3 4 5 6 7 8 9 10 11 12.
DAYS.
PLANTS STARTING IN
QUINTILE I
II
III
IV
V

of two directions, there is a smaller shifting of the mean quintile positions in the intermediate quintiles than in Quintiles I and V. From the preceding facts it appears that seedlings which are small at first frequently surpass in growth, larger ones of equal age.

Let us consider now the specific gravity and the size of the seeds from which these 75 seedlings grew. Of the 15 seedlings which started as the smallest, Quintile I, (Table 50), 7 are from small seeds, 1 from a medium and 7 from large seeds. The 2 seedlings which remain in Quintile I on the last day are from small seeds, the 4 in Quintile II are likewise from small seeds. The seventh seedling from small seeds which started in Quintile I is from a seed of Density 3 and is the smallest seedling of Quintile III. Of the 3 seedlings which, starting in Quintile I, reach Quintile V, all are from large seeds; the 2 largest in this case, are from seeds of Density 3, the third from a seed of Density 5. The 2 seedlings in Quintile IV are also from large seeds. The seedling from the medium seeds is in Quintile III. Of the 16 seedlings which start in Quintile II (Table 51), 10 are from small, 5 from medium and 1 from large seeds. The 6 seedlings which fall back into Quintile I are all from small seeds. The 1 which reaches Quintile IV is from a large seed. In Quintile III, (Table 52), 7 of the original 17 are from small, 8 are from medium and 2 from large seeds. The 3 seedlings which, starting in Quintile III recede to Quintile I, are from small seeds. The 4 ending in Quintile II are also from small seeds. Of the 5 which end in Quintile V, 1 is from a large seed, the other 4 from medium seeds. The second seedling from large seeds starting in Quintile III falls just below Quintile V. All of the seedlings which start in Quintile IV (Table 53) are from medium seeds. Of the 5 which reach Quintile V, 2 are from seeds of Density 1 and 3 from those of Density 3. Ten of the 15 seedlings which start in Quintile V, (Table 54), are from medium seeds, the other 5 are from small seeds. On the last day, 3 of those from small seeds are the seedlings in Quintile I, the other 2 are in Quintile II. Of those which remain in Quintile V, 1 is from a medium seed of Density 1, the other is from a medium seed of Density 3.

Out of the 75 seedlings in the group in question, 29 are from small, 36 from medium and 10 from large seeds. Of the 29 seedlings from small seeds, regardless of their position on the first day, 14 are in Quintile I, 14 are in Quintile II and 1 is in Quintile III on the last day. The final distribution of the seedlings from the large seeds is 4 in Quintile V, 4 in Quintile IV and 2 in Quintile III. From the foregoing statements the following conclusions seem justified:

(1) Seedlings which are small at first frequently surpass in growth, larger ones of equal age;

(2) The size and specific gravity of the seeds, chiefly the former, are more definitely correlated with growth than is the initial height of seedlings of the same age.

SUMMARY

Common garden bean seed was separated into 6 groups of different densities by the use of sodium nitrate of 1.32, 1.27, 1.22, 1.17, and 1.12 specific gravity. The seeds of each of the densities were then grouped according to length into small, medium and large.

Seedlings from seeds of each size and density were grown in the dark at 25°C. Seedlings from small and medium seeds of each density were also grown in the dark at 20° and 30°.

Daily measurements were taken and from this data the daily growth increments were determined. When growth ceased both the fresh and the dry weight of the seedling was obtained.

A study of the results made evident that:

(1) Seedlings grown from seeds of 1.32, 1.27, 1.22, 1.17, 1.12 and 1.12–specific gravity differ in amount and rate of growth.

(2) The greatest height and diameter of shoot, also the greatest dry weight, for seedlings from seeds of uniform size is found in those grown from seeds of 1.22, 1.27 and 1.32 specific gravity, seeds of 1.22 or 1.27 usually ranking first.

(3) The greatest fresh weight is, in general, found in seedlings grown from seeds of 1.32, 1.27 and 1.22 specific gravity.

(4) The lower and specific gravity of the seed, the shorter the second and third internodes of the seedlings from seeds of equal size.

(5) The greatest rate of growth, for seedlings from seeds of uniform size, is usually found in seedlings from seeds of 1.32, 1.27 or 1.22 specific gravity.

(6) From the total dry weight it may be inferred that at 25°C the seedlings from seeds of Density 6 use their reserved material to the best advantage.

(7) Seedlings grown from small, medium and large seeds differ in amount and rate of growth.

(8) The total amount of growth varies directly with the length of the seed.

(9) Size and weight of seedlings from seeds of uniform specific gravity show a wider variation (more especially at 25°C) between those from small and medium seeds than between the ones from medium and large.

(10) Seedlings from seeds of medium length show a greater growth rate than seedlings from either small or large seeds of equal specific gravity.

(11) From the total dry weight it may be inferred that, except at 20°C, seedlings from the large and medium seeds use their reserve material to better advantage than those from small seeds.

(12) Seedlings grown in water contain a smaller per cent of water than those from seeds of the same specific gravity and size grown in soil. They are also less brittle.

(13) The root system of seedlings grown in soil is larger than that of seedlings grown in water.

(14) The growth equation of Blackman does not apply to seedlings grown in the dark.

(15) A difference in level in the insertion of the cotyledons on the axis is not correlated with the fresh and dry weights of either root, shoot or plant.

(16) Seedlings which are small at first frequently surpass in growth larger ones of equal age.

(17) The size and specific gravity of the seeds are more definitely correlated with growth than is the initial height of seedlings of the same age.

The author wishes to thank Professor Charles F. Hottes, not only for suggesting the problem, but also for his kindly criticisms and helpful suggestions during the progress of the work.

BIBLIOGRAPHY

1. Blackman, V. H.: The Compound Interest Law and Plant Growth. (Annals of Botany, 33:353-360, 1919.)
2. Clark, V. A.: Seed Selection According to Specific Gravity. (N. Y. Agri. Exp. Sta. Bull. 256, 1904.)
3. Degrully, L.: Sélection des blés et autres semences par la densité. (Le Progrès Agricole & Viticole, 30:453-455, 1898.)
4. Dehérain, P. P. et Dupont, C.: Culture du blé au champ d'expériences de Grignon, en 1902. (Compt. Rend. de l'Acad. des Sci., 135:654-657, 1902.)
5. DeVries, H.: The Mutation Theory, Vol. I, (1909).
6. Haberlandt, F.: Ueber den Einfluss das Samens auf den Ernteertrag. (Böhmisches Centralblatt für die gesammte Landeskultur, 1866:4, Abst. in Hoffmann Jahresbereicht Agr. Chem., 9:298-300, 1868.)
7. Harris, J. A.: Further Studies on the Interrelationship of Morphological and Physiological Characters in Seedlings of Phaseolus. (Brooklyn Bot. Gard., Memoirs 1:167-174, 1918.)
8. Ill. State Water Survey: Analysis of the Mineral Content of Tap Water of the University of Ill. (Lab. No. 30486, 1915.)
9. Johannsen, W.: Elemente der Exakten Erblichkeitslehre. Zweite Auflage. (1913.)
10. Kiesselbach, T. A., and Helm, C. A.: Relation of Size of Seed and Sprout Value to the Yield of Small Grain Crop. (Neb. Agr. Exp. Sta. Res. Bull. 11, 1917.)
11. Leighty, C. E.: Correlation of Characters in Oats. (Amer. Breeders' Ass. Rpt. 7 & 8: 50-61, 1911 & 1912.)
12. Love, H. H.: A Study of the Large and Small Grain Question, (Amer. Breeders' Ass. Rpt. 7 & 8:109-118, 1911 & 1912.)
13. Meyers, C. H.: Effect of Fertility Upon Variation and Correlation in Wheat. (Amer. Breeders' Ass. Rpt. 7 and 8; 61-74, 1911, 1912.)
14. Pearl R., and Surface, F. M.: Growth and Variation in Maize, (Zeit. Indukt. Abstammungs and Vererbungslehre, 14:97-203, 1915.)
15. **Reed, H. S.: Growth and Variability in Helianthus. (Amer. Jour.** Bot. 6:252-271, 1919.)
16. Sanborn, J. W.: Selection of Seed. (Utah Agr. Exp. Sta. Rpt. 1892:133-137.)
17. Woolny, E.: Untersuchungen ueber die Werthbestimmung der Samen als Saat und Handelswaare. (Jour. für Landwirthschaft, 25:75-116, 133-169, 1877.)

TABLE 18.

Series A | WATER CULTURE | SMALL SEEDS
Temperature 25° C

Average Daily Growth Increments in Centimeters

Density	IH	1	2	3	4	5	6	7	8	9	10	11	TH
						HYPOCOTYL							
1	1.83	1.62	3.90	3.30	.43	.01							11.09
2	1.85	4.05	4.47	1.53	.21								12.11
3	1.29	3.59	4.12	1.45	.20								10.65
4	1.47	2.03	4.73	2.38	.30	.04							10.95
5	1.50	2.17	4.17	2.56	.71	.11							11.23
6	1.25	3.07	5.23	2.27	.33	.02							12.17
						FIRST INTERNODE							
1		.26	.47	1.63	3.45	3.13	1.59	.45	.16	.01			11.15
2		.40	.77	1.84	3.68	2.94	1.56	.56	.19	.01			11.95
3		.36	.75	2.34	3.60	2.86	1.29	.40	.15				11.75
4		.28	.50	1.54	3.96	3.11	1.66	.53	.25	.01			11.84
5		.24	.36	1.13	2.81	2.90	1.84	.70	.10	.03			10.11
6		.27	.59	1.58	3.30	2.63	1.32	.50	.13	.07			10.37
						SECOND INTERNODE							
1				.04	.10	.16	.21	.41	.35	.25	.08	.05	1.65
2				.04	.15	.05	.13	.20	.29	.07	.01		.94
3				.10	.15	.06	.17	.30	.20	.08	.03	.01	1.10
4				.08	.10	.09	.10	.16	.18	.18	.02		.91
5				.03	.10	.13	.08	.16	.17	.19	.13	.03	1.01
6					.10	.15	.02	.08	.08	.05			.48
						THIRD INTERNODE							
1							.01	.01	.05	.01			.08
2								.01	.03	.03			.06
3							.01	.03	.01			.01	.06
4									.01	.04	.01		.06
5									.01	.03			.04
6									.02				.02
						SHOOT							
1	1.83	1.89	4.37	4.96	3.98	3.30	1.81	.88	.56	.27	.07	.05	23.97
2	1.85	4.45	5.25	3.40	4.04	2.99	1.69	.77	.50	.11	.01		25.06
3	1.29	3.95	4.87	3.88	3.95	2.93	1.47	.72	.36	.08	.03	.03	23.56
4	1.47	2.30	5.24	3.99	4.36	3.24	1.76	.69	.45	.24	.04		23.78
5	1.50	2.41	4.52	3.71	3.63	3.14	1.93	.86	.29	.24	.13	.03	22.40
6	1.25	3.33	5.80	3.85	3.74	2.80	1.34	.58	.23	.08			23.00

Density	Average Wt. & Length of Seed (gram)	(mm)	Average Fresh Weight in grams of Root	Shoot	Plant	Average Dry Weight In grams of Root	Shoot	Plant	Average Diam. (mm)
1	.2666	10.7	.3269	1.3800	1.7069	.0170	.1010	.1180	2.6
2	.2581	10.8	.3318	1.3084	1.6402	.0184	.0941	.1125	2.7
3	.2757	10.8	.3648	1.3596	1.7244	.0196	.0992	.1188	2.7
4	.2526	10.4	.3197	1.2845	1.6042	.0164	.0931	.1095	2.6
5	.2227	10.5	.3024	1.1356	1.4380	.0157	.0839	.0996	2.5
6	.1713	10.1	.2212	.9623	1.1835	.0124	.0657	.0781	2.3

IH—Height when placed in temperature case. TH—Total height.

TABLE 19.

Series B — WATER CULTURE — MEDIUM SEEDS
Temperature 25°C

Average Daily Growth Increments in Centimeters

Density	IH..	1	2	3	4	5	6	7	8	9	10	11	12	TH
						HYPOCOTYL								
1	1.94	4.32	5.35	1.84	.10									13.55
2	2.25	4.60	4.58	2.14	.07									13.64
3	1.84	5.50	6.33	1.34	.05									15.05
4	1.86	4.21	5.24	.94	.09									12.34
5	1.43	2.10	6.59	3.44	.87	.01	.06							14.47
6	1.84	3.27	6.17	3.06	.53	.11								14.99
						FIRST INTERNODE								
1		.44	.84	2.99	4.17	2.52	.84	.16						11.96
2		.40	.66	2.29	4.61	3.85	1.60	.51	.15					14.08
3		.44	1.28	2.90	4.05	2.51	.94	.30	.06	.02	.02			12.50
4		.51	1.10	3.74	3.85	1.53	.63	.25	.06					11.66
5		.33	.51	1.81	4.16	4.67	2.64	.97	.34	.06	.01			15.51
6		.33	.57	1.81	5.24	3.70	1.51	.63	.24	.01				14.06
						SECOND INTERNODE								
1				.15	.31	.91	2.36	2.98	1.19	.41	.10	.05		8.46
2				.06	.18	.21	.42	1.24	1.53	.52	.10			4.26
3			.04	.16	.20	.66	2.23	1.84	1.14	.42	.06	.01		6.76
4			.18	.14	.16	.84	.98	.73	.36	.21	.05			3.64
5				.01	.04	.20	.23	.40	.57	.36	.23	.16		2.20
6				.01	.09	.24	.40	.47	.54	.49	.24	.07	.06	2.61
						THIRD INTERNODE								
1							.15	.25	.15	.14	.10	.05		.84
2								.04	.16	.08				.28
3							.11	.15	.16	.18	.08	.05		.73
4								.05	.08	.05	.03			.20
5										.04	.01	.04		.10
6								.03	.01	.04	.03	.01	.01	.14
						FOURTH INTERNODE								
3										.05	.01			.06
						SHOOT								
1	1.94	4.76	6.19	4.97	4.59	3.44	3.35	3.39	1.34	.55	.20	.10		34.81
2	2.25	5.00	5.34	4.49	4.86	4.06	2.02	1.79	1.84	.60	.10			32.25
3	1.84	5.94	7.63	4.40	4.30	3.18	3.28	2.29	1.36	.67	.15	.06		35.10
4	1.86	4.73	6.33	4.85	4.08	1.69	1.46	1.27	.86	.41	.24	.05		27.83
5	1.43	2.43	7.10	5.27	5.07	4.89	2.90	1.37	.91	.46	.26	.20		32.29
6	1.84	3.60	6.74	4.89	5.86	4.06	1.91	1.13	.80	.54	.27	.09	.07	31.80

	Average Wt. & Length of Seed		Average Fresh Weight in grams of			Average Dry Weight In grams of			Average Diam.
	(gram)	(mm)	Root	Shoot	Plant	Root	Shoot	Plant	(mm)
1	.4407	13.7	.3495	2.1925	2.5420	.0239	.1715	.1954	3.1
2	.3851	12.9	.3240	1.8985	2.2225	.0199	.1492	.1691	2.9
3	.3915	13.5	.3002	2.0435	2.3437	.0197	.1519	.1716	3.0
4	.3134	13.1	.3501	1.6348	1.9849	.0191	.1164	.1355	2.8
5	.3290	13.1	.3259	1.6671	1.9930	.0195	.1216	.1411	2.9
6	.2915	13.3	.3139	1.5851	1.8990	.0169	.1148	.1317	2.7

TABLE 20

Series C — WATER CULTURE — LARGE SEEDS

Temperature 25°C

Den-sity	IH	1	2	3	4	5	6	7	8	9	10	11	12	TH
		Average Daily Growth Increments in Centimeters												
							HYPOCOTYL							
1	1.80	2.40	5.65	2.25	.05									12.15
2	1.87	2.93	5.13	2.33	.10									12.37
3	1.13	1.37	3.47	3.97	2.33	.22								12.48
4	1.10	2.05	4.92	4.33	1.08	.10								13.58
5	1.70	3.00	4.40	3.63	.83									13.55
							FIRST INTERNODE							
1		.40	1.15	4.35	4.15	2.25	.70	.15						13.15
2		.43	.85	3.73	4.25	3.18	.62	.12						13.18
3		.30	.33	.72	2.77	4.95	3.22	.97	.28	.03				13.57
4		.28	.27	1.23	2.75	4.47	3.17	.80	.15					13.12
5		.30	.35	1.25	3.00	4.70	2.90	.50	.13					13.13
							SECOND INTERNODE							
1			.25	.30	1.20	3.70	2.70	1.05	.35	.15				9.70
2				.30	.45	1.52	3.90	2.38	.68	.13				9.37
3				.03	.15	.40	1.20	2.67	2.13	.82	.38	.12		7.90
4					.12	.30	.65	1.80	1.55	.58	.42	.18		5.60
5					.08	.37	.75	1.38	1.30	.63	.15	.05	.02	4.93
							THIRD INTERNODE							
1						.35	.15	.25	.20	.15	.10	.15	.10	1.15
2						.12	.28	.37	.28	.08	.03			1.17
3							.12	.18	.18	.15	.08	.02		.73
4								.12	.12	.03	.07	.03		.37
5								.10	.15	.08	.10	.02		.45
							FOURTH INTERNODE							
1													.05	.05
							SHOOT							
1	1.80	2.80	6.80	6.85	4.50	3.50	4.55	3.10	1.25	.50	.25	.15	.15	36.20
2	1.87	3.37	5.98	6.37	4.80	4.82	4.80	2.87	.97	.18	.07			36.08
3	1.13	1.66	3.80	4.71	5.25	5.56	4.57	3.81	2.62	1.03	.46	.13		34.73
4	1.10	2.32	5.20	5.55	3.95	4.88	3.82	2.73	1.82	.60	.50	.20		32.68
5	1.70	3.30	4.75	4.88	3.90	5.07	3.65	2.18	1.57	.70	.25	.10	.02	32.07

	Average Wt. & Length of Seed		Average Fresh Weight in grams of			Average Dry Weight In grams of			Average Diam.
	(gram)	(mm)	Root	Shoot	Plant	Root	Shoot	Plant	(mm)
1	.4957	16.2	.5499	2.4527	3.0026	.0295	.1872	.2167	3.3
2	.5272	16.1	.6445	2.5433	3.1878	.0331	.2059	.2391	3.5
3	.5174	16.9	.3644	2.6313	2.9957	.0271	.2099	.2370	3.5
4	.3966	15.8	.3347	2.1359	2.4706	.0193	.1629	.1822	3.1
5	.4147	15.3	.2699	2.1988	2.4687	.0189	.1699	.1888	3.2

TABLE 37

Series D — **SOIL CULTURE** — **SMALL SEEDS**

Temperature 25°C

Density	IH	1	2	3	4	5	6	7	8	9	10	11	TH
	Average Daily Growth Increments in Centimeters												
	HYPOCOTYL												
1	1.63	2.40	5.37	5.08	.26								14.76
2	2.11	3.70	5.60	.98	.04								12.43
3	2.26	3.55	4.61	1.74	.10								12.26
4	2.11	2.79	6.55	2.75	.14								14.34
5	1.29	2.58	5.71	4.13	.37								14.08
6	2.36	3.26	5.70	1.89	.06								13.27
	FIRST INTERNODE												
1		.23	.53	2.31	3.94	1.77	.51	.14	.03				9.47
2		.45	1.38	3.05	2.58	.84	.25	.07					8.62
3		.41	1.11	2.59	2.49	1.18	.32	.08	.01				8.19
4		.31	.91	2.85	3.29	1.14	.21	.08	.01				8.80
5		.24	.53	1.56	2.99	2.02	.46	.15					7.95
6		.36	.76	2.61	2.94	1.06	.17	.03					7.91
	SECOND INTERNODE												
1				.16	.18	.26	.57	.49	.21				1.87
2			.11	.17	.14	.30	.50	.24	.06	.01			1.54
3			.01	.11	.18	.14	.18	.16	.05	.01			.84
4			.03	.14	.19	.21	.35	.16	.06	.01	.01		1.16
5				.09	.12	.09	.05	.10	.01	.01	.01		.48
6			.11	.16	.16	.13	.10						.66
	THIRD INTERNODE												
1							.03	.04	.03				.10
2							.04	.04	.01	.01			.10
3							.03	.01					.04
4							.01	.04	.01				.06
5												.01	.01
6								.03					.03
	SHOOT												
1	1.63	2.64	5.90	7.56	4.38	2.03	1.11	.67	.27				26.20
2	2.11	4.15	7.10	4.20	2.75	1.14	.79	.35	.08	.02			22.69
3	2.26	3.96	5.74	4.44	2.76	1.31	.53	.25	.06	.01			21.32
4	2.11	3.10	7.49	5.74	3.61	1.35	.58	.27	.09	.01	.01		24.36
5	1.29	2.81	6.24	5.77	3.49	2.11	.51	.25	.01	.01	.01	.01	22.51
6	2.36	3.61	6.46	4.61	3.14	1.21	.30	.16					21.85

Density	Average Wt. & Length of Seed (gram)	(mm)	Average Fresh Weight in grams of Root	Shoot	Plant	Average Dry Weight In grams of Root	Shoot	Plant	Average Diam. (mm)
1	.2881	11.0	.3424	1.6683	2.0107	.0200	.1091	.1291	2.8
2	.2665	10.7	.3252	1.5319	1.8571	.0219	.0994	.1213	2.8
3	.2444	10.8	.2609	1.4573	1.7182	.0190	.0907	.1097	2.7
4	.2429	10.5	.2203	1.4990	1.7193	.0163	.0937	.1100	2.5
5	.2164	10.3	.1504	1.2380	1.3884	.0148	.0801	.0949	2.5
6	.1983	10.8	.1343	1.1577	1.2920	.0157	.0762	.0919	2.4

TABLE 38

Series E — SOIL CULTURE — MEDIUM SEEDS

Temperature 25°C

Density	IH	1	2	3	4	5	6	7	8	9	10	11	TH
		Average Daily Growth Increments in Centimeters											
						HYPOCOTYL							
1	2.84	4.39	6.27	1.70									15.20
2	2.67	4.37	5.96	1.99	.27								15.26
3	2.29	3.53	8.11	4.07	.19								18.19
4	2.54	3.21	7.03	2.86	.15								15.79
5	2.10	3.21	8.03	3.67	.39	.04							17.44
6	3.14	5.04	6.48	.68	.04								15.38
						FIRST INTERNODE							
1		.41	1.31	3.24	2.91	1.21	.49	.15					9.73
2		.44	1.51	3.23	3.06	.67	.27	.07					9.26
3		.29	.79	3.19	3.88	1.89	.56	.17	.01				10.78
4		.40	1.06	3.40	3.14	1.13	.42	.15					9.70
5		.33	.80	2.74	4.30	2.27	.40	.11	.03				10.99
6		.62	1.54	4.30	3.12	.92	.26	.06	.04				10.86
						SECOND INTERNODE							
1			.03	.22	.29	.85	2.13	1.40	.19	.07			5.18
2			.03	.27	.34	.93	1.46	.86	.26	.01			4.16
3				.20	.36	.51	1.11	1.03	.31	.19	.03		3.74
4				.24	.23	.32	.84	.60	.20	.01			2.44
5				.13	.23	.37	.56	.79	.31	.03	.01		2.43
6			.04	.18	.30	.40	.44	.40	.20	.06			2.02
						THIRD INTERNODE							
1							.13	.18	.01	.01			.33
2						.03	.09	.07	.04	.04			.27
3								.05	.09	.07			.21
4								.04	.04	.03			.10
5								.04	.01	.01	.01		.07
6									.02	.02			.04
						SHOOT							
1	2.84	4.80	7.61	5.16	3.20	2.06	2.74	1.73	.20	.09			30.43
2	2.67	4.81	7.50	5.49	3.67	1.63	1.81	1.00	.30	.06			28.94
3	2.29	3.81	8.90	7.46	4.43	2.40	1.68	1.25	.41	.26	.02		32.91
4	2.54	3.61	8.09	6.46	3.53	1.44	1.26	.81	.25	.04			28.03
5	2.10	3.54	8.83	6.54	4.91	2.69	.96	.94	.36	.04	.03		30.94
6	3.14	5.66	8.06	5.16	3.46	1.32	.70	.46	.36	.08			28.30

Density	Average Wt. & Length of Seed (gram)	(mm)	Average Fresh Weight in grams of Root	Shoot	Plant	Average Dry Weight In grams of Root	Shoot	Plant	Average Diam. (mm)
1	.4176	13.3	.4172	2.3848	2.8020	.0294	.1630	.1924	3.3
2	.4215	13.3	.4485	2.5520	3.0005	.0327	.1659	.1986	3.2
3	.3579	13.3	.3072	2.4495	2.7567	.0228	.1407	.1635	3.1
4	.3354	13.0	.3574	2.0892	2.4466	.0266	.1293	.1559	3.1
5	.3334	13.2	.2886	2.0904	2.3790	.0235	.1288	.1523	3.0
6	.3072	13.4	.5046	1.9502	2.4548	.0294	.1206	.1500	3.0

TABLE 39

Series F					SOIL CULTURE								LARGE SEEDS Temperature 25°C
Den-sity	IH	1	2	3	4	5	6	7	8	9	10	11	TH
					HYPOCOTYL								
2	2.17	3.17	5.90	2.07	.11								13.42
3	2.22	2.75	5.25	3.60	.27								14.08
4	2.93	5.07	4.83	.53									13.36
5	2.53	3.33	6.25	2.60	.18								14.90
					FIRST INTERNODE								
2		.53	1.67	3.99	3.53	1.14	.44	.14	.03	.01			11.48
3		.33	.80	2.65	4.63	2.50	.67	.15					11.73
4		.63	2.23	3.63	2.83	1.03	.23	.13					10.73
5		.38	1.08	3.35	3.70	1.32	.18	.07	.02				10.10
					SECOND INTERNODE								
2			.10	.27	.49	1.39	1.49	.54	.19	.04			4.50
3				.15	.33	.92	2.33	1.77	.45	.03			5.98
4			.03	.23	.47	.83	.90	.43	.07				2.97
5				.27	.40	.63	1.12	.43	.20	.01			3.06
					THIRD INTERNODE								
2						.04	.13	.07	.03	.03			.30
3						.05	.10	.15	.07				.37
4						.03	.07	.03	.07				.20
5						.12	.02	.05					.18
					SHOOT								
2	2.17	3.70	7.67	6.33	4.13	2.57	2.06	.76	.24	.09			29.71
3	2.22	3.08	6.05	6.40	5.23	3.47	3.10	2.10	.52	.03			32.17
4	2.93	5.70	7.10	4.40	3.30	1.90	1.20	.60	.13				27.27
5	2.53	3.72	7.33	6.22	4.28	1.95	1.42	.52	.27				28.25

	Average Wt. & Length of Seed (gram)	(mm)	Average Fresh Weight in grams of Root	Shoot	Plant	Average Dry Weight In grams of Root	Shoot	Plant	Average Diam. (mm)
2	.4421	15.6	.2043	2.4114	2.6157	.0287	.1719	.2006	3.4
3	.4658	16.2	.4839	2.7125	3.1964	.0360	.1904	.2264	3.3
4	.4162	15.7	.6050	2.5739	3.1790	.0310	.1718	.2028	3.3
5	.3887	15.6	.3402	2.3250	2.6652	.0260	.1585	.1845	3.1

The cost of printing necessitates the omission of the data from which the following tables are derived:

TABLE 50

Quintile Distribution on Successive Days for Seedlings Starting on Quintile I.

Quintile	1	2	3	4	5	6	7	8	9	10	11	12	Total*
I	15	8	8	5	4	3	2	3	3	2	2	2	42
II	0	6	6	7	7	6	5	5	4	5	4	4	59
III	0	1	0	2	4	4	5	3	3	3	4	4	33
IV	0	0	0	1	0	2	2	2	2	2	2	2	15
V	0	0	1	0	0	0	1	2	3	3	3	3	16
											Grand Total		165
Mean Quintile Position	1.00	1.53	1.67	1.93	2.00	2.33	2.67	2.67	2.87	2.93	3.00	3.00	

TABLE 51

Quintile Distribution on Successive Days for Seedlings Starting on Quintile II.

Quintile	1	2	3	4	5	6	7	8	9	10	11	12	Total*
I	0	5	4	7	7	6	6	6	6	6	6	6	65
II	16	3	4	1	1	3	3	2	4	4	4	4	33
III	0	8	7	7	6	4	4	6	4	5	5	5	61
IV	0	0	1	1	1	3	3	2	2	1	1	1	16
V	0	0	0	0	1	0	0	0	0	0	0	0	1
											Grand Total		176
Mean Quintile Position	2.00	2.19	2.31	2.13	2.25	2.25	2.25	2.25	2.13	2.06	2.06	2.06	

TABLE 52

Quintile Distribution on Successive Days for
Seedlings Starting on Quintile III.

Quintile	1	2	3	4	5	6	7	8	9	10	11	12	Total*
I	0	2	1	2	3	4	3	3	3	3	3	3	30
II	0	5	5	5	4	2	4	4	3	3	4	4	43
III	17	7	5	2	1	4	3	3	4	4	3	3	39
IV	0	3	5	5	6	1	2	2	2	2	2	2	32
V	0	0	1	3	3	6	5	5	5	5	5	5	43
											Grand Total		187
Mean Quintile Position	3.00	2.65	3.00	3.12	3.12	3.18	3.12	3.12	3.18	3.18	3.12	3.12	

TABLE 53

Quintile Distribution on Successive Days for
Seedlings Starting on Quintile IV.

Quintile	1	2	3	4	5	6	7	8	9	10	11	12	Total*
I	0	0	1	1	1	0	2	1	1	1	1	1	10
II	0	2	0	0	1	2	0	1	1	1	1	1	10
III	0	1	3	2	2	2	1	1	1	1	1	1	16
IV	12	4	1	3	2	2	2	3	4	4	4	4	33
V	0	5	7	6	6	6	7	6	5	5	5	5	63
											Grand Total		132
Mean Quintile Position	4.00	4.00	4.08	4.09	3.92	4.00	4.00	4.00	3.92	3.92	3.92	3.92	

TABLE 54

Quintile Distribution on Successive Days for
Seedlings Starting on Quintile V.

Quintile	1	2	3	4	5	6	7	8	9	10	11	12	Total*
I	0	0	0	0	0	2	2	2	2	3	3	3	17
II	0	0	2	3	3	3	4	4	4	3	3	3	32
III	0	0	2	4	4	3	4	4	5	4	4	4	38
IV	0	5	5	2	3	4	3	3	2	3	3	3	36
V	15	10	6	6	5	3	2	2	2	2	2	2	42
											Grand Total		165
Mean Quintile Position	5.00	4.67	4.00	3.73	3.67	3.20	2.93	2.93	2.87	2.87	2.87	2.87	

*Total distribution exclusive of first day.

VITA

The author received her secondary education at her native city, Woodstock, Illinois. She graduated from the Illinois State Normal University in 1902 after which she taught High School Mathematics and Science for six years. A year and a half was then spent teaching under the Presbyterian Mission Board, in the mountains of Tennessee. The degree of A. B. was received from the University of Illinois in 1911, and that of A. M. from the same University in 1912. Two years were spent as Instructor of Mathematics and Physics at Maryville College, and one year as Assistant Professor of Mathematics at Tusculum College. Since 1916 she has been an Assistant in Botany at the University of Illinois, assisting during the past year and a half chiefly in Plant Physiology.